Long-Period Ground-Motion Simulations of the M_w 7.2 El Mayor-Cucapah Mainshock: Evaluation of Finite-Fault Rupture Characterization and 3D Seismic Velocity Models

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Objective

- Test long-period (T > 2.0 s) ground-motion simulation capabilities with recordings from the 4 April 2010 Mw 7.2 El Mayor-Cucapah earthquake

Methodology

- Use approach of Graves and Pitarka (2010) to generate suite of hypothetical finite-fault ruptures for the El Mayor Cucapah event
- Simulate ground motions using two 3D seismic velocity models: CVM-4m and CVM-H62
- Compare with observed motions at 200+ sites

Results

- Median levels of simulations match observed peak ground velocities reasonably well; standard deviation of residuals generally within 50% of the median
- CVM-4m simulations yield somewhat lower variance across entire model region than those with the CVM-H62 model
- For non-basin regions, CVM-H62 simulations perform better than CVM-4m; attribute to inclusion of Tape et al. (2009) tomographic updates within background of CVM-H62
- Both CVMs tend to over-predict motions in San Diego region and under-predict motions in Imperial basin and Mojave desert
- Within the greater Los Angeles basin, CVM-4m simulations generally match level of observed motions; CVM-H62 simulations over-predict motions in the southernmost portion of the basin
- Variance in residuals is lowest for a rupture with significant shallow slip (less than 5 km depth); variance is greatest for ruptures with deep asperities (below 10 km depth)
- Results provide confidence in the predictive capabilities of the simulation methodology, while also suggesting regions where the seismic velocity models may need improvement

Ground-Motion Observations

The M_w 7.2 El Mayor-Cucapah earthquake occured along a multi-segment fault trace in northern Baja California with a primarily normal-oblique focal mechanism. Ground-motion waveforms of the mainshock were recorded at over 200 strong-motion sites throughout southern California and northern Baja California. Locations of the recording sites for which data were obtained as of 08 April, 2010 are shown in the adjacent figure along with the first 24 hours of aftershocks. Data for these stations were further processed by integrating to ground velocity and low-pass filtering with a corner at 0.5 Hz.

Above figure plots observed PGV for the southern California region. The strongest motions are in the near fault region and extend eastward into the Imperial Valley. With increasing distance from the fault, the spatial distribution of PGV exhibits noticeable complexity and variability. Areas of relatively strong motions occur in the Coachella Valley, the San Bernardino and Mojave regions, and most significantly in the Los Angeles basin region. Areas of relatively weak motions occur west of the Coachella Valley and in the San Diego region. We interpret these features to be related to wave propagation effects within the heterogeneous crustal structure of the southern California region.

Scenario Rupture Models

A suite of five hypothetical kinematic rupture models were generated using the procedure of Graves and Pitarka (2010). We fix the magnitude and hypocenter, and the slip is constrained to have an amplitude spectrum with a wavenumber squared falloff and random phasing. The mean slip is scaled to the mainshock moment (7.8×10^{26} dyne-cm on average) with the standard deviation of slip set at 85% of the mean slip.
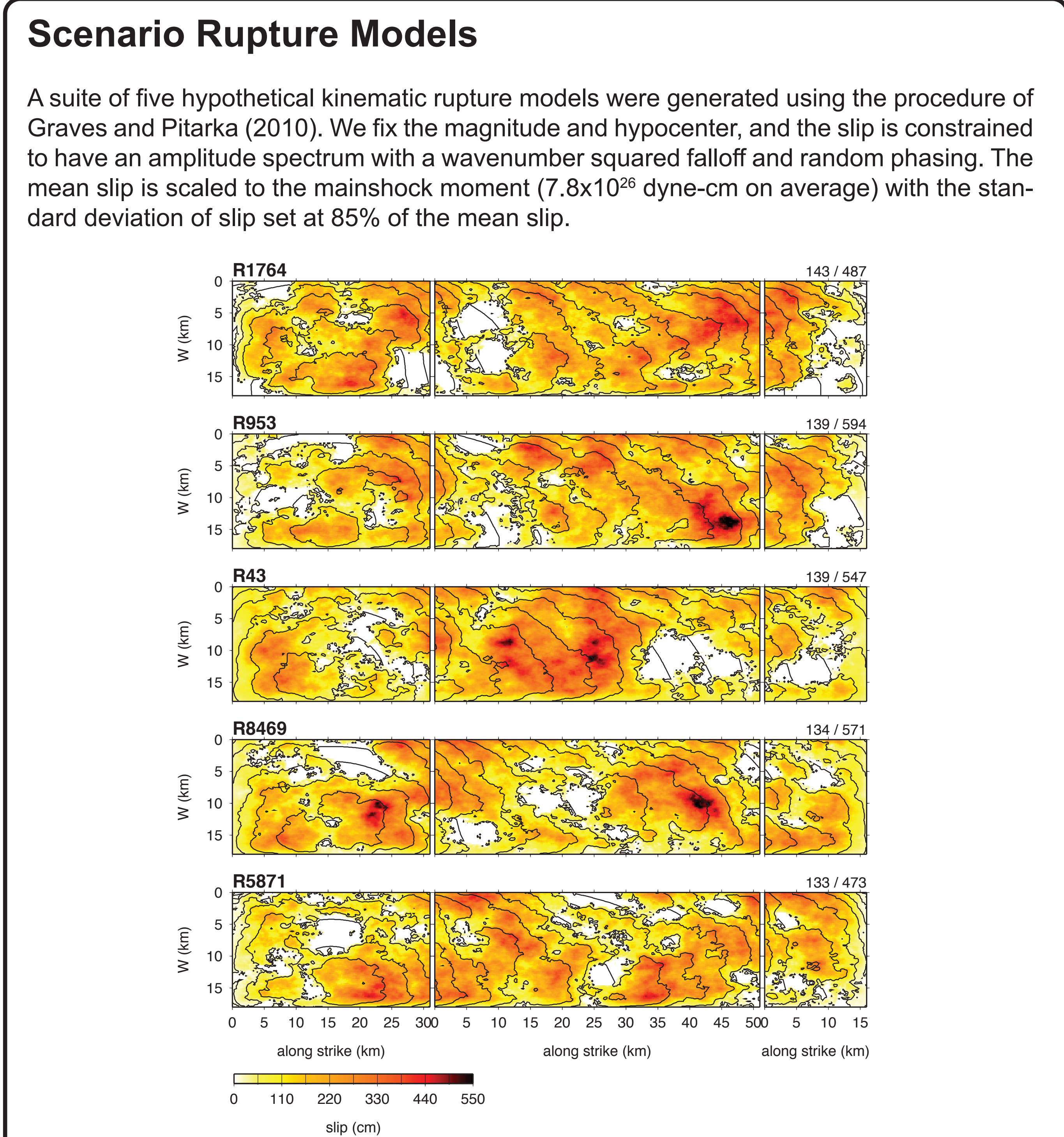

Figure above plots the slip distribution and rupture propagation contours for the five scenarios. Rupture propagation speed is set at 80% of the local shear wave velocity with perturbations dependent on fault segmentation and local slip. Rise time scales with square root of local slip (Aagaard et al., 2008) and lengthens by a factor of two in the upper 5 km of rupture. The average value of rise time is 1.47 sec. The rake is allowed to vary across the fault with a standard deviation of 15 degrees about a prescribed mean value of 200°.

Seismic Velocity Models

We consider two alternative 3D seismic velocity models. The basis for the first model (CVM-4m) is the SCEC CVM-4.0 (Magistrale et al., 2000; Kohler et al., 2003), which is modified by replacing the upper 2 km of the background (i.e., non-basin) structure with the Boore-Joyner generic rock profile (Boore and Joyner, 1997) and replacing the Vp/Vs relation for sediments of the Imperial Valley with the "mudline" relation of Brocher (2005). The second model, CVM-H62, is version 6.2 of the SCEC CVM-H (Shaw and Suess, 2003), and includes the tomographic updates of Tape et al. (2009) within the background crustal structure, as well as the Boore-Joyner generic rock profiles in the shallow (upper 300 m), non-basin portions of the model. Anelastic attenuation is incorporated via quality factors Qs = 50Vs (for Vs in km/s) and Qp = 2Qs. In the near surface layers, we limit the minimum shear velocity to 0.5 km/s, which dictates a grid size of 0.2 km for accurate wave propagation results.

Above figure shows horizontal slices of shear wave velocity in the Los Angeles basin region at a depth of 2 km for models CVM-H62 (left) and CVM-4m (right). Locations of recording sites are indicated by the dark circles. The large arrow indicates the location of station ce13070, which is discussed in the panels to the right.

Simulation Results

Figure below plots ratio of synthetic to observed PGV for the 10 simulations. Rupture R1764 produces the median residual that is closest to zero and the lowest standard deviation; rupture R953 has the greatest positive median residual and largest standard deviation. This suggests that features of rupture R1764 such as the large shallow slip patch near the junction of the second and third segments are more consistent with the observed ground motions, whereas features of rupture R953 such as the generally deeper slip and deep asperity with large slip on the second segment are less consistent with the recorded motions.

The median residual using the CVM-4m model is generally centered about zero, with a standard deviation of roughly 45 to 50% of the median. This model does reasonably well in matching the observed PGV levels in the western Imperial Valley and Los Angeles basin regions; however, it over-predicts the motions in the San Diego region (up to a factor of 2 or greater) and under-predict the motions in the eastern Imperial Valley and northeast of the San Andreas fault in the Mojave desert (up to a factor of 2).

Median residuals for CVM-H62 range from near zero (R5871) to 63% over-prediction (R953), with a standard deviation of roughly 55 to 75% of the median. CVM-H62 strongly over-predicts peak amplitudes in the southernmost Los Angeles basin region, with simulated values 2 to 3 times larger than observed. This leads to the general positive bias in the CVM-H62 simulations and larger standard deviation relative to CVM-4m. Nonetheless, this model does reasonably well in matching the observed PGV in the central and northern LA basin. This model tends to over-predict the motions in San Diego (by roughly 50%) and under predict the motions in the eastern Imperial Valley and east and north of the San Andreas fault (by roughly 50%), although the range of variance is not as strong as that for CVM-4m.

Waveform Comparisons

Figure below compares observed and simulated waveforms for three sites in the central and western portion of the Los Angeles basin region. Both models provide a good fit to the amplitude and duration of the observed waveforms. Station DLA is situated over the deepest portion of the basin, with motions characterized by large amplitude arrivals lasting for at least 40 to 50 seconds, and peak amplitudes over 10 cm/s (about 3 to 4 times larger than the motions at the non-basin site MWC). Station SMS is located along the western margin of the basin where the sediment thickness is about 3 to 4 km. Motions at this site are about 2 to 3 times larger than at MWC, and exhibit large amplitude arrivals lasting at least 50 seconds.

CVM-H62   CVM-4m

Wave Field Animations

Above panels show snapshots of simulated ground velocity for rupture scenario R1764 in both seismic velocity models. Since the rupture occurred along the western boundary of the Imperial Valley, significant wave energy is channeled into the deep sediments of this basin structure, leading to strong amplification of motions and extended durations of strong ground shaking throughout the Imperial and Coachella Valleys. The CVM-4m includes the Laguna Salada basin just to the west of the rupture (green arrow on right panels), and predicts strong amplification and extended durations in this area that are not present in CVM-H62. The animations also clearly demonstrate the CVM-H62 structure produces a much stronger channeling and trapping of wave energy in the southern Los Angeles basin compared to the CVM-4m structure (red arrow at t=90 s). At later times, a strong basin response is evident for both models in the central Los Angeles basin (blue arrow at t=120 s).

Acknowledgements